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(Lunnaya avtomaticheskaya spektrometricheskaya apparatura RIFMA)

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The RIFMA Lunar Automatic Spectrometric Equipment

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The chemical composition of a planetary body belongs to a number of most significant characteristics of the history of its origin and evolution. In the overall study program of the chemical composition of the surfaces of the planetary bodies of the solar system, naturally, the first and foremost object of investigation was the moon.

In investigating the composition of the lunar surface, first of all, it is necessary to establish a general correlation between the distribution of chemical elements on its surface and their distribution on earth. This problem has been partially solved by Soviet scientists in experiments for the investigation of gamma-activity [1] and x-ray radiation [2] of the moon conducted from orbital stations, and through the efforts of American scientists who have conducted element analysis of the small portions of the lunar surface near the landing sites of the Surveyor-5, Surveyor-6, and Surveyor-7 spacecraft [3].

A sufficiently complete program for the investigation of the chemical composition of the moon should include an analysis of many separate sections of the visible and invisible portions of the lunar surface --- regions of seas and continents, craters of different size, "rays", etc., and investigation of the chemical composition according to depth, etc. [4,5].

The above-mentioned investigations can be conducted by lunar stations of various types, directly on the surface or by delivering the soil samples to earth for examination under laboratory conditions.

A large amount of extremely valuable information was provided by the lunar expeditions of the Apollo spaceships and the Luna-16 station, which have delivered to earth samples of the lunar soil from the Sea of Tranquility, Ocean of Storms, and the Sea of Plenty.

There are, however, a number of problems of the structure of the moon and the origin of the shape of the lunar relief which are difficult to solve by the analysis of the chemical composition of the individual small sections of the surface (the type of investigations conducted by the Surveyor equipment), or by laboratory analysis of a strictly limited number of samples collected from a small area and delivered to earth. These important problems of selenology include problems about the degree of similarity of the composition of the surface and the relation of the relief to the chemical composition. To study these problems, it is necessary to investigate the composition of the surface and subsurface layer of the lunar soil within the limits of individual, small surface regions which widely represent the different lunar formations: craters of different size and shape, ridges, fractures, rock fragments, etc. The only possibility for such investigations is the utilization of mobile devices which travel along the lunar surface. The study of the composition of the surface in individual regions, in addition to having independent interest, makes it possible to examine these investigations as a branch of the comprehensive work on the physical mapping of the moon.

In these and many other investigations of the lunar surface, the possibility of using a moon rover [lunokhod] as a mobile laboratory equipped with special analytical instruments is difficult to overestimate. The potential possibilities of such a laboratory can be utilized best only with a correct combination of the moonwalker characteristics (speed, maneuverability, passability) and analytical instruments (informational capacity, speed, capability for repeated measurements).

Let us examine the specifications which must be satisfied by the method of chemical analysis of the lunar surface in a direct experiment, with the consideration of the possibility of conducting this experiment by an automatic station.

At this stage, such a method must provide rapid and repeated delivery of information which is of interest to us, with a complete automation of all processes and with the consideration of the fact that the surface being analyzed is completely unprepared. The instruments must withstand vibration, linear, and shock overloads during the period of the delivery of the instrument to the surface of the moon and not lose its efficiency during prolonged periods of intense space radiation, deep vacuum, and sharp temperature drops from +150° to −170° C.

Finally, in an ideal case, the method and the instruments developed on its basis must provide:

storage of information on board the stations with subsequent transmission to earth;

delivery of information to the cosmonaut in a convenient and sufficiently graphic form.

The equipment for rapid analysis of soil installed on Lunokhod-1 utilizes the x-ray spectrometric method of analysis. The method is based on the fact that any chemical element under certain specific conditions emits a spectrum of x-rays which is inherent only to that element and is called the characteristic spectrum.

The position of the lines in the differential spectrum indicates the presence of certain chemical elements in the sample, and by the intensity of these lines it is possible to determine the relative composition of the corresponding elements. The nature of the x-ray radiation is such that these spectra are much simpler than, for example, the optical spectra. X-ray methods of spectrochemical analysis have a high sensitivity, and are a convenient and reliable method of determining the chemical composition of substances. An advanced method of x-ray analysis is fluorescent (emission) spectroscopy. In this method, x-ray tubes are usually used for activating the characteristic radiation of the sample, and the analysis of fluorescent x-ray radiation is conducted by the dispersal of the radiation into a spectrum by means of crystals.

The achievements of the physics and technology of radioactive radiation detectors and nuclear electronics permit, in a number of cases, to eliminate the application of the dispersal methods of analysis and to use the so-called non-crystal (nondispersal) methods, which leads to a significant simplification of equipment. To analyze radiation of a sample according to energy, energy sensitive detectors of ionizing radiation are used (scintillation, proportional, and semiconductor counters), together with spectrometric amplifiers and pulse amplitude analyzers.

A progressive trend of x-ray fluorescent analysis is the use of radioactive sources, instead of x-ray tubes. These sources do not require an electrical supply, nor adjustment and debugging, and are reliable, lightweight and compact.

In the RIFMA equipment, radioactive sources are used to activate the x-ray radiation of soil. The registration of x-ray quanta emitted by the sample is conducted by an energy sensitive detector whose pulses are input to an electronic device for processing.

In accordance with these principles, the RIFMA equipment contains radioactive sources which irradiate lunar soil, detectors which register the x-ray radiation of soil, and electronic devices. Naturally, only the sources and the detectors must be located in the direct proximity of the investigated surface (Fig. 54).

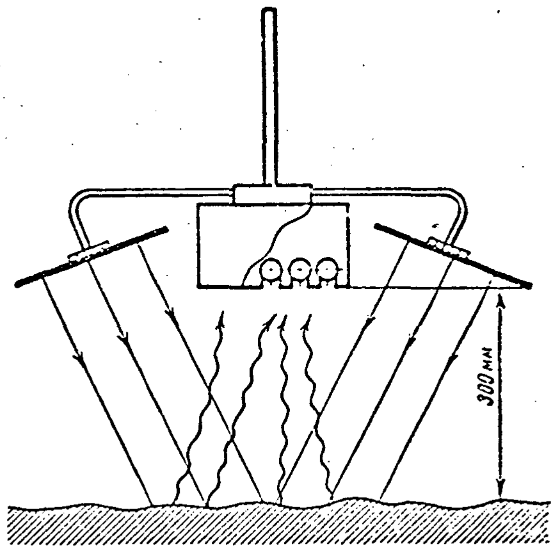


Fig. 54. The geometry of the RIFMA experiment. Two radioactive sources irradiate the soil. X-ray radiation of soil is registered by the system of detectors.

Therefore, in developing the equipment, a modular principle was used. The RIFMA on-board instruments consist of three modules: the portable module located outside of the instrument compartment of the moon rover, and an electronic module and a pulse-digital converter module which are located inside the instrument compartment of the moon rover. The signal transmission circuit of the RIFMA equipment is shown in Figure 55. The portable module (PM) houses the radioactive sources, detectors of soft x-ray radiation, a preamplifier-commutator, temperature-sensitive elements, and a thermoregulation system. The portable module is securely fixed in

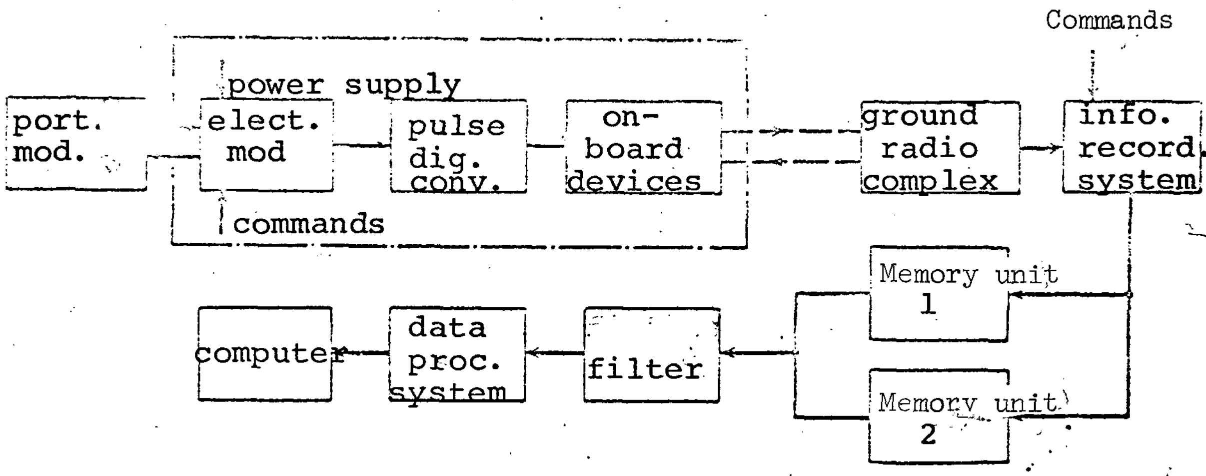


Fig. 55. The Signal Transmission Circuit of the RIFMA Equipment

the front part of the Lunokhod-1, between the wheels at the height of about 300 mm from the soil.

The RIFMA equipment utilizes x-ray radiation sources based on H^3. Due to their high specific activity, it was possible to obtain extremely compact and light sources, which effectively activate fluorescent radiation with energy below 10 kev, i.e., in the area where the K-lines of the radiation of the basic rock-forming elements are located. The sources being used are stable in relation to the external effects: vibrations, shocks, temperature drops, prolonged period of vacuum, etc.

Gas-discharge proportional, soft x-ray radiation counters with thin external windows are used as detectors of x-ray radiation of soil. There are several models of sealed-off and flow proportional counters used to investigate soft x-ray radiation. Most often flow-type counters are used. The preference in selecting flow counters is explained, to a large degree, by the possibility of significantly increasing the efficiency of registration of soft radiation by the installation of a thinner window of larger dimensions. In a flow counter, the windows, the most vulnerable element of the unit, are not required to meet the strict specifications of mechanical durability or airtightness.

According to the conditions of our experiment, the use of a flow system of counters was excluded.

At present, there is no industrial model of a sealed-off proportional radiation counter which, according to its physical features, would be on the level of the best laboratory models, and at the same time, would meet the strict specifications stemming from the conditions of prolonged experiment in space and on the lunar surface.

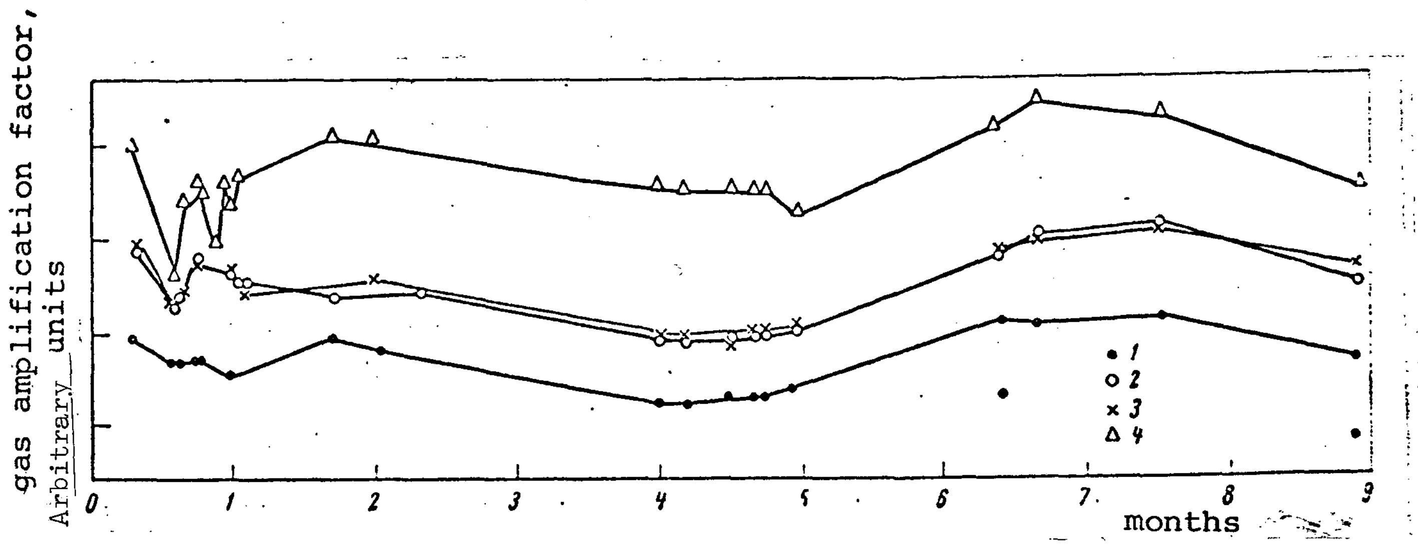
Several versions of counters have been developed and investigated, both of the laboratory type and those to be installed in flight equipment.

The investigation of these counters and of the methods of their production made it possible to arrive at the best version of design. The technological aspects of counter production are such that it is possible to produce large batches of counters with identical characteristics under the existing laboratory base conditions.

The proportional counter of the suggested design has the required physical characteristics (efficiency of registration of soft x-ray radiation, the size of the gas amplification factor, energy resolution), is stable against the action of a wide range of temperatures and vibrations, and is highly reliable, which is especially important since the counter will be used in prolonged investigations in open space and on the lunar surface. Fig. 56 shows the experimental data about the stability properties of the counters in prolonged tests.

In the lower portion of the RIFMA instrument module, several counters are installed in one row with the side windows turned to the soil.

Due to the theoretical impossibility for a proportional counter to resolve the radiation lines of neighboring elements, selective filters are used in the non-dispersion analysis.



'Fig. 56. Time dependence of the position of the reference source line for several sealed-off proportional, soft x-ray radiation counter models.

In the ordinate axis - one graduation corresponds to a 20 percent change of the gas amplification factor.

In the equipment installed in the moon rover, the individual detectors are equipped with filters which allow determining separately the intensity of K-lines of the more representative rock-forming elements.

According to the conditions of the experiment, the portable module is thermo-insulated from the moon rover; therefore, it was necessary to thermostatically control the detectors and the preamplifier-commutator. A thermostatic control system was developed for the portable module. As indicated by laboratory investigations, and by the experiments with the moon rover, the thermostatic control system provides for the necessary range of temperatures over a long period of time, during the change in temperature of the lunar surface ranging from -170° to +140° C.

The methodology of measuring the chemical composition using the RIFMA instrument provides for obtaining a differential energy spectrum of x-ray radiation of soil. In accordance with the goal of the experiment, the electronic circuit includes the usual elements used in spectrometric measurements: an amplifier and a multichannel amplitude analyzer, and a stable high voltage source for supplying the proportional counters used as detectors.

The development of the RIFMA equipment was conducted with the consideration of specific requirements set for instruments operating in space objects (low consumption, small dimensions and weight; reliable operation at a wide range of temperatures). In the development, the possibility of loads and the parameters of the communication channel was also considered.

Let us examine briefly the functional designation and the specific features of the design of the basic circuitry (see Fig. 55).

X-ray radiation detectors are located in the portable module (PM). To ensure freedom from interference and the capability to operate with a cable require the positioning of a charge-sensitive preamplifier in a direct proximity of the detectors. A preamplifier based on 1Zh24B core tubes with a K= 10 amplification factor was developed for the RIFMA device. The amplifier also provides alternate connection of detectors to the amplifier input. From the output of the preamplifier via the cable, the pulses are transmitted to the instrument compartment, where the amplifier and the pulse-digital converter (PDC) are located.

The main amplifier is located in the electronic module (EM). It is assembled according to the differential amplifier scheme with impact load and has two amplification cascades with amplification factors of 15 and 16 correspondingly. In the first cascade, a dual shaping of signals is realized: capacitive, and on the delay line with $\tau_{shaping} = 2 \cdot 10^{-6}$ sec. The connections inside the cascade are made by galvanization. In addition to the main amplifier, the electronic module houses a stabilizer (stability 1%) and a high voltage source.

The high voltage source is used to ensure the operation of the proportional counters. Since the amplification factor greatly depends on the power supply, this source must meet very rigid specification. In the RIFMA equipment, a supplementary stabilizer, operating jointly with the transformer and a multiplier circuit, is used to obtain the high voltage. The voltage at the output of the circuit is 1340 v. The high voltage stability in relation to time and in a temperature range from -5 to +40°C is 0.06% and the efficiency is 80 percent.

The stabilizer is made according to a circuit having the conversion of the d-c current error signal into the a-c. The correction of errors occurs at a high voltage in the phase detector circuit.

The electronic module houses the command device which is a combination of a set of relays which connect or disconnect the device, on command from the on-board complex, and a scaling circuit with a decoder which switches the amplifier-commutator.

The pulse-digital converter circuit is actually an input device of the multichannel analyzer.

The pulse-digital converter converts the pulse into a digital code which corresponds to its amplitude. The rapid operation of the communication channel and the capability of continual operation during the entire period of measurements made it possible to connect a more complex and cumbersome device which executes a channel-by-channel registration and storage of information in the ground complex. This made it possible to significantly increase the reliability of the on-board equipment and decrease its dimensions and weight. An additional advantage of the pulse-by-pulse transmission is the possibility of examining the dynamics of processes registered by the detectors.

In the terminal transmission band of the communication channel, for a specific time interval, the product of the number of symbols in a code word (a) by the number of words (b) a·b=const.-- i.e., the number of channels of the analyzer is selected in accordance to the requirement of reliable resolution of lines. In the RIFMA instrument, a 64-channel amplitude analyzer is used to register the differential spectrum, and a code word contains six information symbols. To ensure interference-free operation, two additional symbols are used: one is a marker pulse of double amplitude used to divide the message, the other is a parity check pulse. Along with the information messages, the pulse-digital converter also transmits code messages which correspond to errors and overflow. The latter are used to estimate the true intensity and the intensity of radiation which leave in the detector the energy of E_{ut} (E_{ut} is the upper threshold of energy).

From the pulse-digital converter output, the pulses are transmitted to the on-board radio complex and then to the communication channel.

The logic behind the design of the ground complex of the RIFMA unit is based on the effort to provide the most complete storage of information transmitted from aboard. In accordance to this specification, a block diagram which includes a memory unit was developed.

Let us examine in sequence the process of storage and processing of information in the ground RIFMA complex.

From the output of the receiving device, the envelope is transmitted to the input of the information recording system (IRS). In the recording system, the necessary amplification or attenuation of the signal is conducted and it is filled with a high frequency (5 kHz) to retain the "0" level of the constant component. Later the information is recorded on magnetic tape.

In processing the information from the output of the memory device, the modulated messages are transmitted to the input of the low-frequency filter which has a plane frequency characteristic. In it, the envelope is separated and is transmitted to the input of the data processing system which contains a cycle generator with an automatic frequency control of the frequency of code messages, an intermediate memory register, and a parity and storage check unit where channel-by-channel registration is executed. Addressed storage of messages is conducted only if the parity corresponds. The individual channels are used to register the number of counting losses or overflows. In addition, the data processing system has outputs of the total number of registered pulses and the output of the number of distorted messages which do not correspond to parity.

The RIFMA automatic spectrometric unit has successfully endured the launching, lunar landing, and the difficult conditions of lunar experiment. During several lunar days, this equipment can provide noncontact, rapid analysis of the chemical composition of the lunar soil along the Lunokhod-1 traveling course in the Sea of Rains.

The chemical composition of many areas with characteristic geological-morphological features has been investigated. The undisturbed surface, craters of different age (including the individual details of craters: bottom, incline, ridges) rocks at a depth of 10 cm which were uncovered by special maneuvers of the moon rover, and individual rocks were studied.

Along with this, a comprehensive examination of a number of sections of the lunar surface was conducted: in one section, both the physical-mechanical properties and the chemical composition were determined. A number of experiments of scientific-technical and methodological nature were conducted. In the course of the experiments, it was proven that the RIFMA equipment can operate both during the moon rover stops, or when it is in motion.

During the several months the RIFMA equipment was in operation, several hundreds of x-ray spectra have been obtained. The interpretation of the experimental data has not been completed and, to a large degree, depends on the processing of the total experimental data from the Lunokhod-1.

The table shows a summary of the results of the determination of the chemical composition of different regions of the lunar surface and the results obtained in the Sea of Rains via the RIFMA equipment on Lunokhod-1. This data substantiates the general concept about the origin of regolith being the result of the crushing of the rocks, basically of basalt composition.

The specific aspects of spectrometric features of the RIFMA equipment made it possible, along with a specific chemical composition, to obtain interesting data about the variations of intensities of solar and galactic cosmic rays.

The authors feel obliged to mention the immense role of the late Academician B. P. Konstantinov, Vice President of the USSR Academy of Sciences, in the formulation of the problem and providing the possibility for conducting the experiment.

The Chemical Composition of the Lunar Surface (Weight %)

Element	Sea of Tranquility			Central Bay *	Ocean of Storms *		Tycho Crater *		Sea of Plenty **		Sea of Rains ***
	Surveyor -5	Apollo-11		Surveyor -6	Apollo-12		Surveyor-7		Luna-16		Lunokhod-1
	Fines	Fines	rock	Fines	Fines	rock	Fines	rock	Fines	rock	Fines
Si	21	20	20	23	20	19	21	21	20	20	20
Fe	9	12	14	10	13	17	4	3	13	15	12
Ca	10	8	7	9	7	8	13	13	9	7	8
Al	8	6	6	8	7	6	11	14	8	7	7
Mg	3	5	5	4	7	7	4	<2	5	4	7
Ti	4	5	6	2	2	2	<0,4	<0,7	2	3	<4
K	-	0.1	0.2	-	0.3	0.05	-	-	0,08	0,12	<1
Na	0.5	0.4	0.4	0.6	0.3	0.3	0.5	0.3	0.3	0.2	-

*L. D. Jaffe, Paper, t. 1, XIII COSPAR. Leningrad, 1970
**A. P. Vinogradov. Pravda, October 29, 1970.
***This work; preliminary results.

<u>References</u>

1. A. P. Vinogradov, Yu. A. Surkov et. al., (*Kosmich. issled.*), 1967, 5. No. 6, 874.

2. S. L. Mandel'shtam, I. P. Tindo et. al. (*Kosmich. issled.*), 1968, 6, No. 1, 119.

3. A. L. Turkevich, E. Y. Franzgrote, Y. H. Patterson. *Science*, 1969, 165, 277.

   E. Y. Franzgrote e. al. Science, 1970, 167, 376.

4. B. P. Konstantinov, M. M. Bredov, S. V. Viktorov, G. V. Kir'yan, G. E. Kocharov, V. O. Naydenov, Doklady Akademii Nauk SSSR, 1968, 181, 827.

5. S. V. Viktorov, G. V. Kir'yan, G. E. Kocharov, Report of the Physico-Technical Institute named after A. F. Ioffe of the USSR Academy of Sciences (Otchet Fiziko-tekhnicheskogo in-ta im. A. F. Ioffe AN SSSR), 1968, No. 0-217.